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RHIC PROJECT

Brookhaven National Laboratory

Solenoid Effects and Correction in RHIC

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1. Introduction

The possible orbit effects due to the STAR solenoid in RHIC have been studied. The linear coupling effects due to the solenoid have been found to be small compared to the effects due to the random skew quadrupole field errors in the magnets. It does not appear necessary to add any additional skew quadrupole correctors. The skew quadrupole correctors provided to correct the effects due to random skew quadrupole field errors in the magnets will be able to correct the linear coupling effects due to the solenoid.

It would be worthwhile to do some tracking studies to check for possible non-linear effects due to the solenoid. This requires a more detailed knowledge of the magnetic field shape of the solenoid. A method for describing the non-linear magnetic field of the solenoid, which is convenient for entering it into a tracking program, has been worked out so that the tracking study can be done when the field data becomes available.

There are several reasons why tracking studies may be desirable for RHIC. The PHENIX axial field magnet, which appears to have stronger non-linear fields than the STAR solenoid, will also be present. While solenoids and axial field magnets have been used in previous accelerators, RHIC appears to be different as it requires a large aperture and has strong non-linear fields from the accelerator magnets.

2. Linear Coupling Effects Due to a Solenoid

An analytical treatment of the linear coupling effects due to solenoids was given by Guignard who also suggested that the solenoid effects could be corrected using skew quadrupoles.[1,2] A different treatment of this subject was given by V. Garczynski[3]. In RHIC, there are strong linear coupling effects[4] due to the random skew quadrupole errors in the magnets. It will be seen below, that the linear coupling effects due to the STAR solenoid are considerably smaller than the effects due to random skew quadrupole errors. Thus the correction system provided in RHIC for the linear coupling effects due to random skew quadrupole errors should be able to correct the linear effects of the solenoid as well.

The linear coupling effects may be estimated from the driving term, $\Delta\nu$, for the nearby different resonance. $\Delta\nu$ may be visualized as a resonance width inside which the coupling is strong. $\Delta\nu$ is also a rough measure of the tune shift due to the linear coupling fields. $\Delta\nu$ is given by[1]

$$\Delta\nu = \frac{1}{4\pi\rho}\int ds\,(\beta_x\beta_y)^{1/2}\left\{a_1 - \frac{1}{2}c_0\left[\frac{\alpha_x}{\beta_x} - \frac{\alpha_y}{\beta_y} + i\left(\frac{1}{\beta_x} + \frac{1}{\beta_y}\right)\right]\right.$$
$$\left.\exp\left[i\left(-\overline{\nu}_x\theta_x + \overline{\nu}_y\theta_y\right)\right]\right\} \tag{2.1}$$

$$\overline{\nu}_x = \frac{1}{2}(\nu_x + \nu_y + p), \qquad \overline{\nu}_y = \frac{1}{2}(\nu_x + \nu_y - p)$$
$$\theta_x = \psi_x/\nu_x, \qquad \theta_y = \psi_y/\nu_y$$

ν_x, ν_y are assumed to be close to the resonance $\nu_x - \nu_y = p$. On the median plane, the fields are given by

$$\begin{aligned} B_x &= -B_0\ a_1\ x \\ B_s &= -B_0\ c_0. \end{aligned} \tag{2.2}$$

For the STAR solenoid $B_s = 5$ kG, the effective length is $L = 7.06$ m, and $c_0 = .14$.

Neglecting the edge effects, Eq. (2.1) gives for the contribution to $\Delta\nu$ of the solenoid

$$\Delta\nu = 0.33 \times 10^{-3} \qquad \text{solenoid.} \tag{2.3}$$

This $\Delta\nu$ is quite small compared to the $\Delta\nu$ expected from the random skew quadrupole fields in the magnets. A simulation study[4] shows a maximum expected $\Delta\nu$ for $\beta^* = 2$ of

$$\Delta\nu = 100 \times 10^{-3} \qquad \text{magnets.} \tag{2.4}$$

At the edge of solenoid, there are transverse fields B_x, B_y. The a_1 at each end may be estimated from

$$\int a_1 ds = \frac{1}{2}\frac{B_s}{B_0}, \tag{2.5}$$

and $\int a_1 ds = 0.073$ for the STAR solenoid.

Eq. (2.1) gives a contribution to $\Delta\nu$ due to each end of the solenoid whose magnitude is

$$\Delta\nu = 0.14 \times 10^{-3} \qquad \text{solenoid edge} \tag{2.6}$$

Also, in RHIC, the two edge effects tend to cancel each other. The end effects may be more important for possible non-linear effects.

3. Possible Non-Linear Effects

It is difficult to decide whether the non-linear effects of the solenoid are worth worrying about. However, one should keep in mind that the solenoid is a strong magnet; the linear effects are small, partly because the field is largely a longitudinal field which is not as effective as a transverse field in producing transverse forces. The non-linear transverse fields at the ends might generate appreciable non-linear effects. Also the PHENIX axial field magnet will also be present in RHIC, and it appears to have a more non-linear field than the STAR solenoid. While solenoids and axial field magnets have been used in previous accelerators, RHIC appears to be different as it requires a large aperture and has strong non-linear fields from the accelerator magnets.

An important problem here is to provide a way of describing the complicated non-linear field of the solenoid so that it can be conveniently entered into a tracking program. One solution for the STAR solenoid is that the non-linear transverse field B_r be described as a set of point multipoles at each end, and the longitudinal field B_s be described by 3 sets of point multipoles, one at the center and one at each end. It is suggested that B_r have multipoles up to r^7 and B_s have multipoles up to r^6. B_r has only odd multipoles and B_s has only even multipoles.

The field data required to enter the multipoles includes $\int B_s\ ds$ and $\int B_r\ ds$ where these integrals are evaluated as follows: For $\int B_s ds$, the $\int B_s ds$ should be provided over the center flat region and over each end. In each region the $\int B_s ds$ has to be expanded as

$$\int B_s\ ds = B_0\left(c_0 + c_2 r^2 + c_4 r^4 + c_6 r^6\right)$$

For the $\int B_r ds$, the $\int B_r ds$ should be provided over each end and $\int B_r ds$ has to be expanded as

$$\int B_r\ ds = B_0\left(d_1 r + d_s r^3 + d_5 r^5 + d_7 r^7\right)$$

A plot of B_s and dB_r/ds as a function of s at $r = 0$ is needed in order to determine where the point multipoles should be located.

The tracking program will have to be modified to handle longitudinal point multipoles.

4. References

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